AD-258855

BIMONTHLY REPORT

on

DEVELOPMENT OF PROCEDURES FOR WELDING 2-INCH-THICK TITANIUM-ALLOY PLATE

to

BUREAU OF NAVAL WEAPONS
DEPARTMENT OF THE NAVY

April 30, 1961

by

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May 26, 1961

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DEVELOPMENT OF PROCEDURES FOR WELDING 2-INCH-THICK TITANIUM-ALLOY PLATE

Research is being conducted to develop procedures for welding thick titanium-alloy plates. This research is part of an over-all program to evaluate thick titanium-alloy plate for use in deep-diving submarines. Weldments that have high strength in combination with good ductility and toughness are required for submarine hulls. The specific objectives of the research are to develop procedures to:

(1) Obtain sound ductile welds in 2-inch-thick plate

(2) Obtain joint efficiencies of 100 per cent

(3) Obtain satisfactory toughness in weldments.

The following is a list of welds made prior to this report period in 30-inch-long, 2-inch-thick titanium-alloy plates:

Base Plate	Filler Wire	Heat Input, joules/inch
Ti-6Al-4V	Ti-6Al-4V	45,000
Ti-6Al-4V	Ti-5Al-2.5Sn	45,000
Ti-6Al-4V	A-55	45,000
Ti-5Al-2.5Sn	Ti-5Al-2.5Sn	45,000
A-70	A-55	45,000

In addition to these, Lehigh and NRL restraint tests were made on each of the three base plates, using filler wire that matched the composition of the base plate. Cracking has not been a problem in any of these welds.

Joint efficiencies of at least 100 per cent were obtained for all except those made in Ti-6Al-4V and A-70 base plates with A-55 filler wire. In these latter two welds, weld-metal strength was below that of the base plate. Notch toughness of all welds in general was equal to or greater than that of the base plate.

During this report period, the following welds were made in 30-inch-long, 2-inch-thick plate:

Base Plate	Filler Wire	Heat Input, joules / inch
Ti-6Al-4V	Ti-6Al-4V	21,000
Ti-5Al-2.5Sn	Ti-5Al-2.5Sn	27,000
Ti-5Al-2.5Sn	Ti-6Al-4V	45,000
Ti-5Al-2.5Sn	A-55	45,000
A-70	Ti-6Al-4V	45,000

In addition, a weld was deposited manually in 1/2-inch-thick Ti-6Al-4V base plate, using a Ti-6Al alloy filler wire. The amount of filler material was limited, and only enough weld metal for notch-toughness data was obtained.

This report covers the period from February 28 to April 30, 1961.

SUMMARY

During this report period, low-heat-input welds were made in the Ti-6Al-4V and Ti-5Al-2.5Sn alloy base plate, using filler wire that matched the composition of the base plate. Two additional welds were made in the Ti-5Al-2.5Sn base plate, using Ti-6Al-4V and A-55 filler wires. Also, a weld was made by depositing Ti-6Al-4V alloy filler wire in A-70 base plate in an attempt to obtain a weld metal with improved ductility and notch toughness and with good strength. No cracking was encountered in any of these welds.

Impact and tensile properties of the low-heat-input welds made in Ti-6Al-4V and Ti-5Al-2.5Sn base plates using matching filler wires were about the same as those obtained in similar welds made with a high heat input. Notch toughness was at least equal to or greater than that of the base plate in each case. In the welds made by depositing

TABLE 1. SUMMARY OF ALL DATA OBTAINED TO DATE[a]

Material	Filler Metal	Heat Input, joules per inch	Composition, per cent								Ultimate Tensile Strength, 1000 psi		Tensile Yield Strength, 1000 psi		Elongation in 2 Inches, per cent		Reduction in Area, per cent		Notch Toughness[b], ft-lb			
			Al	V	Sn	Fe	C	N	H_2	O_2	Long.	Trans.	Long.	Trans.	Long.	Trans.	Long.	Trans.	Room Temp	0 F	–40 F	–80 F
										Ti-6Al-4V												
Base Metal	–	–	6.13	4.16	–	0.10	0.01	0.011	0.0056	0.121	132	134.5	115	119	11	8	21	16	21	20	18	16
Filler wire	–	–	6.78	4.06	–	0.11	0.01	0.011	0.0150	0.112	–	–	–	–	–	–	–	–	–	–	–	–
Weld metal	Ti-6Al-4V	45,000	6.26	4.16	–	0.11	0.02	0.011	0.0046	0.131	144	135.	128	(c)	6	(c)	9	(c)	20	17.5	18	16.5
Weld metal	Ti-5Al-2.5Sn	45,000	5.58	1.22	2.30	0.32	0.04	0.011	0.0096	0.143	138.5	137.5	131	(c)	11	(c)	19	(c)	21.5	15	16.5	14
Weld metal	A-55	45,000	1.75	1.05	–	0.10	0.03	0.014	0.0042	0.133	93	104	83	92	17.5	6	39	29	40	32	26	21.5
Weld metal	Ti-6Al-4V	21,000	6.28	4.08	–	0.11	0.04	0.012	0.0092	0.105	148	138.5	133	(c)	5	(c)	10	(c)	18	17.5	14.5	15
Weld metal	Ti-6Al	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	36.5	–	–	38.5
										Ti-5Al-2.5Sn												
Base metal	–	–	5.38	–	2.43	0.12	0.07	0.018	0.0027	0.154	136	136.5	128.5	131.5	13	4	25	11	13	10	9	8
Filler wire	–	–	6.15	–	2.57	0.4	0.01	0.012	0.029	0.100	–	–	–	–	–	–	–	–	–	–	–	–
Weld metal	Ti-5Al-2.5Sn	45,000	5.09	–	2.60	0.23	0.05	0.015	0.0113	0.084	138	137	125	(c)	8	(c)	12	(c)	18	15	13	11
Weld metal	Ti-5Al-2.5Sn	27,000	5.35	–	2.58	0.37	0.04	0.013	0.0192	0.157	–	–	–	–	–	–	–	–	18	14	15	12.5
Weld metal	Ti-6Al-4V	45,000	5.95	3.06	1.70	0.12	0.03	0.012	0.0110	0.119	141	131	127	(c)	11	(c)	16	(c)	10	9	9	6.5
Weld metal	A-55	45,000	1.13	–	0.63	0.11	0.06	0.016	0.0067	0.169	87	–	76.5	–	21	–	34	–	25.5	25	22.5	18.5
										A-70												
Base metal	–	–	–	–	–	0.09	0.03	0.007	0.0073	0.317	97	98	80.5	88	27	25	54	60	12	9.5	12.5	8
Filler wire	–	–	–	–	–	0.12	0.01	0.014	0.0059	0.148	–	–	–	–	–	–	–	–	–	–	–	–
Weld metal	A-55	45,000	–	–	–	0.11	0.03	0.013	0.0060	0.177	82.5	–	69	–	24	–	44	–	17	13	14	13
Weld metal	Ti-6Al-4V	45,000	4.82	3.26	–	0.10	0.04	0.011	0.0090	0.171	134	98	120	(c)	8.5	(c)	15.5	(c)	26.5	22	21.5	19

(a) All tensile values are averages of two tests.
(b) Base-metal impact properties are averages of two tests for Charpy bars taken in three directions with respect to the rolling direction. Weld-metal impact properties are averages of two tests.
(c) Transverse tension specimens failed in the base metal.

Ti-6Al-4V filler wire in Ti-5Al-2.5Sn base plate, the tensile properties were about equal to those of the base plate, and the impact properties were very low. The use of A-55 filler wire in Ti-5Al-2.5Sn base plate resulted in impact properties considerably better than those of the base plate. The strength of this weld metal, because of the low alloy content, was low, resulting in a 65 per cent joint efficiency.

In an effort to obtain a weld metal with some intermediate Al-V composition, Ti-6Al-4V filler wire was deposited in A-70 base plate. A weld-metal composition of 4.82 per cent aluminum and 3.26 per cent vanadium was obtained. The impact properties of the weld metal were higher than those of the base plate. A yield strength of 120,000 psi and elongation of 8.5 per cent were obtained for this weld metal.

A weld was made also by manually depositing a high-purity Ti-6Al filler wire in Ti-6Al-4V base plate. Only enough weld metal was obtained for Charpy vee-notch impact tests. The impact properties of this weld were the best obtained to date; impact energy was 36.5 ft-lb at room temperature and 38.5 ft-lb at -80 F. Although tensile data were not obtained from this weld, the yield strength should at least approach 120,000 psi.

A summary of all data obtained so far in the program is shown in Table 1.

WELDING AND TESTING PROCEDURES

All welds were made in an argon-filled chamber with the consumable-electrode welding process. A constant-potential power source connected for reverse polarity was used to supply welding current. All filler wire was 1/16 inch in diameter and was cleaned in acetone prior to welding.

A 45-degree double-vee-type joint with a 1/8-inch land was used for all welds. All joints were cleaned in acetone and pickled in a 40 per cent HNO_3, 2 per cent HF, and 58 per cent water solution prior to welding. The welding conditions that were used are shown in Table 2.

TABLE 2. WELDING CONDITIONS USED IN MAKING THE WELDS

Type of Weld	Filler Wire	Weld Travel Speed, ipm	Wire Feed Speed, ipm	Arc Voltage, volts	Weld Current, amperes	Heat Input, joules/inch	Contact-Tube-to-Work Distance, inch	Interpass Temperature, F	Number of Passes
				Ti-6Al-4V					
30 inch	Ti-6Al-4V	30	450	33	320	21,000	7/8	--	20
				Ti-5Al-2.5Sn					
30 inch	Ti-5Al-2.5Sn	25	450	33.5	340	27,000	7/8	100-150	17
30 inch	Ti-6Al-4V	15	450	33	340	45,000	7/8	120-190	11
30 inch	A-55	15	450	32.5	375	49,000	7/8	80-200	13
				A-70					
30 inch	Ti-6Al-4V	15	450	33	340	45,000	7/8	90-190	10

Standard 0.505-inch-diameter tension specimens and standard Charpy vee-notch impact specimens were used to obtain tensile and impact data.

Side-bend specimens 6 inches long, 1-1/2 inches wide, and 3/16 inch thick were used to obtain bend ductility. Bend tests were made by bending the specimens around dies of different radii until a crack was observed. The radii decreased from 2 to 1-1/2 inches, and then by 1/4-inch intervals down to 3/4 inch and by 1/16-inch intervals down to a zero radius. The minimum bend radius was taken as the radius of the smallest die that the specimen passed without cracking.

Hardness data were obtained using a Vickers diamond pyramid hardness testing machine with a 10-kg load.

RESULTS AND DISCUSSION

Welds in the three base plates, Ti-6Al-4V, Ti-5Al-2.5Sn, and A-70, were evaluated during this report period. Matching filler wire was used in the Ti-6Al-4V base plate. Matching filler wire, Ti-6Al-4V, and A-55 filler wires were used in the Ti-5Al-2.5Sn base plate. Ti-6Al-4V filler wire was used in the A-70 base plate. In general, filler wires of different composition than that of the base plate were used to see if impact properties and ductility could be improved without sacrificing other weld properties.

Mechanical Properties

Tensile properties of the welds made during this report period are shown in Table 3. Base-metal tensile properties and the properties of previous welds in Ti-6Al-4V and Ti-5Al-2.5Sn base plates are included in Table 3 for comparison.

TABLE 3. WELD-METAL TENSILE PROPERTIES[a]

Material	Filler Wire	Ultimate Tensile Strength, 1000 psi		Tensile Yield Strength[b], 1000 psi		Elongation in 2 Inches, per cent		Reduction in Area, per cent		Heat Input, joules/inch
		Long.	Trans.	Long.	Trans.	Long.	Trans.	Long.	Trans.	
				Ti-6Al-4V						
Base metal	--	132	134	115	119	11	8	21	16	--
Weld metal	Ti-6Al-4V	144	135[c]	128	(c)	6	(c)	9	(c)	45,000
Weld metal	Ti-6Al-4V	148	138.5[c]	133	(c)	5	(c)	10	(c)	21,000
				Ti-5Al-2.5Sn						
Base metal	--	136	136.5	128.5	131.5	13	4	25	11	--
Weld metal	Ti-5Al-2.5Sn	138	137[c]	125	(c)	8	(c)	12	(c)	45,000
Weld metal	Ti-5Al-2.5Sn	--	--	--	--	--	--	--	--	27,000
Weld metal	Ti-6Al-4V	141	131[c]	127	(c)	11	(c)	16	--	45,000
Weld metal	A-55	87	--	76.5	--	21	--	34	--	45,000
				A-70						
Base metal	--	97	98	80.5	88	27	25	54	59	--
Weld metal	Ti-6Al-4V	134	98[c]	120	(c)	8.5	(c)	15	(c)	45,000

(a) All tensile properties are averages of two tests.
(b) Yield strength taken at 0.2 per cent offset.
(c) Weld-metal transverse specimens failed in the base metal.

No significant differences were noted in the tensile properties when using different heat inputs (45,000 and 21,000 joules/inch) for the two welds made in Ti-6Al-4V base plate with matching filler wires. The ultimate and yield strengths of both were above those of the base plate, while the elongation of both was lower than that of the base plate.

No tensile data were obtained for the low-heat-input weld in the Ti-5Al-2.5Sn base plate. However, from results obtained with the Ti-6Al-4V base plate, differences in tensile properties would not be expected with small changes in heat input.

Welds in Ti-5Al-2.5Sn base plate made with Ti-6Al-4V filler wire had yield strength and elongation about equal to that of the base plate, and as would be expected, welds made in Ti-5Al-2.5Sn base plate using A-55 filler had only a 65 per cent joint efficiency.

The yield strength of the weld made with Ti-6Al-4V filler wire in A-70 base plate was well above that of the A-70 base plate. In fact, the yield strength of this weld was higher than that of the Ti-6Al-4V base plate. The elongation of this weld was considerably lower than that of the A-70 base plate and about equal to that of the Ti-6Al-4V base plate.

Notch-toughness data obtained for low- and high-heat-input welds made in Ti-6Al-4V and Ti-5Al-2.5Sn base plates using matching filler wires are compared in Table 4. As shown by these data, notch toughness was not affected by changes in heat input. A summary of the remaining notch-toughness data for base metals and weld metals is shown in Figure 1.

TABLE 4. COMPARISON OF NOTCH TOUGHNESS OF WELDS MADE AT DIFFERENT HEAT INPUTS

Base Metal	Filler Wire	Heat Input, joules/inch	Notch Toughness[a], ft-lb				
			RT	0 F	-40 F	-60 F	-80 F
Ti-6Al-4V	Matching	45,000	20	17.5	18	17	16.5
Ti-6Al-4V	Matching	21,000	18	17.5	14.5	14	15
Ti-5Al-2.5Sn	Matching	45,000	18	15	13	13.5	11
Ti-5Al-2.5Sn	Matching	27,000	18	14	15	13.5	12.5

(a) All notch-toughness data are averages of two tests.

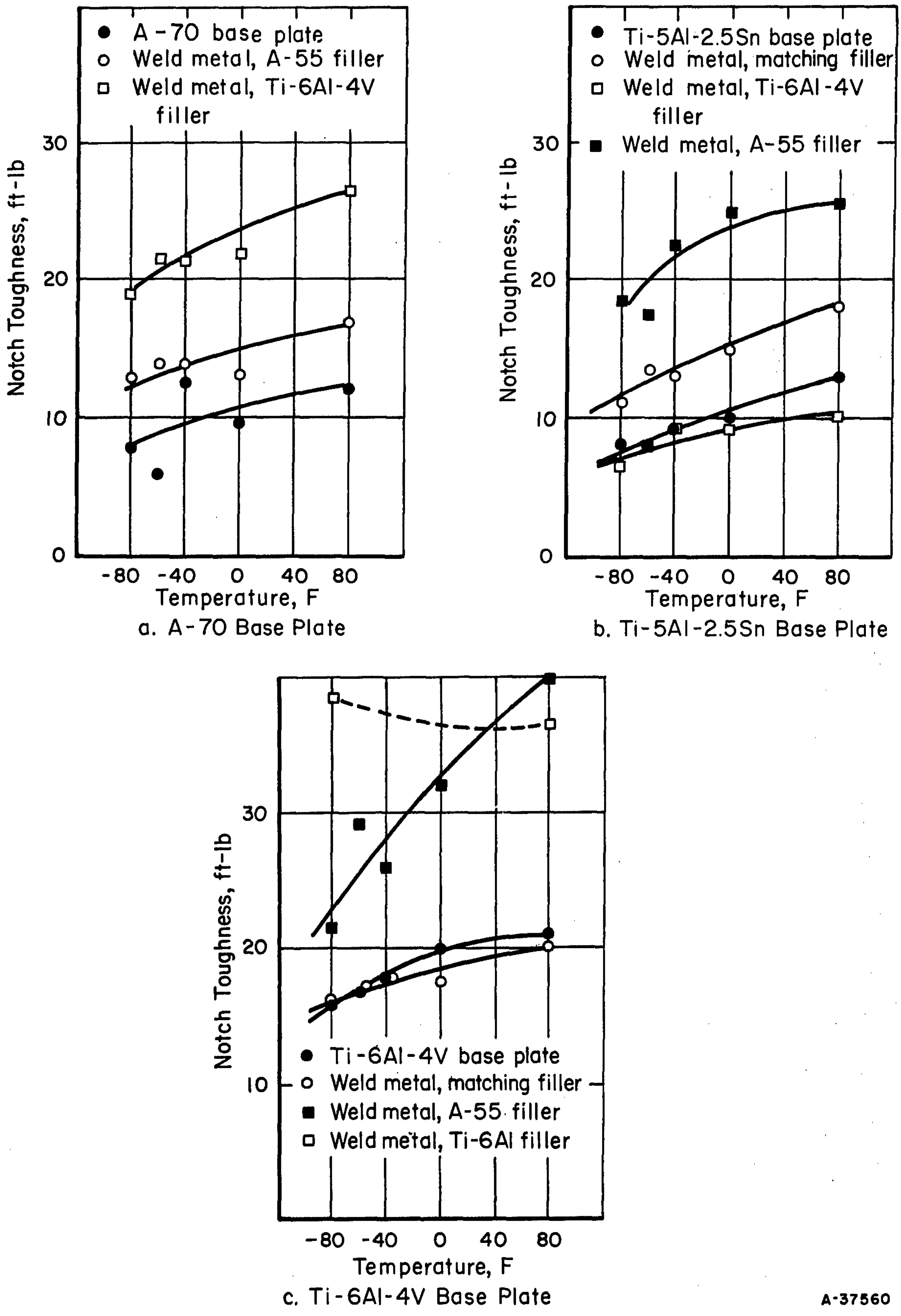


FIGURE 1. NOTCH TOUGHNESS OF BASE PLATE AND WELD METALS

In Figure 1a, the impact properties of weld metals in A-70 are compared with the impact properties of A-70 base plate. The toughness of all weld metals was higher than that of the base plate. The weld made with Ti-6Al-4V filler wire had the highest notch toughness of any of the welds made to date in the A-70 base plate. The notch toughness and the yield strength of this weld exceeded that of the Ti-6Al-4V base plate. The alloy content of this weld metal was 4.82 per cent aluminum and 3.26 per cent vanadium.

In Figure 1b, the notch toughness of weld metals in Ti-5Al-2.5Sn is compared with that of the base plate. Here again, the weld-metal impact properties are as good or better than the impact properties of the base plate. The highest weld-metal properties were obtained when A-55 filler wire was used. This weld metal contained about 1.13 per cent aluminum and 0.63 per cent tin. However, the joint efficiency was only 65 per cent. Figure 1c compares the notch toughness of welds made in the Ti-6Al-4V base plate. The notch toughness of the weld made in Ti-6Al-4V base plate when using high-purity Ti-6Al filler wire was considerably higher than either the base plate or the weld made in this base plate with matching filler wire. Although chemical analysis could not be made, it was estimated that the weld metal contained about 6 per cent aluminum and very little vanadium, probably about 1 per cent. This weld was made manually by the inert-gas tungsten-arc process in an argon-filled welding chamber. Because of the small amount of filler wire available, only enough weld metal for two Charpy bars was obtained.

Bend ductility for welds made to date are shown in Table 5. None of the weld metals tested had bend ductilities as good as that of the base plate. In general, welds made with the A-55 filler wire had better bend ductility than any of those made with either the Ti-6Al-4V or Ti-5Al-2.5Sn filler wires. No significant differences were noted between welds made with Ti-6Al-4V and Ti-5Al-2.5Sn filler wires in any of the base plates. As shown in Table 4, Ti-6Al-4V and Ti-5Al-2.5Sn base plates had about equal bend ductility, while that of the A-70 base plate was considerably better. A summary of all hardness data obtained to date is given in Table 6.

TABLE 5. BEND-TEST DATA FOR BASE PLATES AND WELDS MADE TO DATE[(a)]

Base Metal	Filler Wire	Heat Input, joules/inch	Minimum Bend Radius, T	
			Long.	Trans.
Ti-6Al-4V	--	--	4	--
Ti-6Al-4V	Ti-6Al-4V	45,000	10.5	--
Ti-6Al-4V	Ti-6Al-4V	21,000	8.5	--
Ti-6Al-4V	Ti-5Al-2.5Sn	45,000	--	--
Ti-6Al-4V	A-55	45,000	--	--
Ti-5Al-2.5Sn	--	--	5.5	--
Ti-5Al-2.5Sn	Ti-5Al-2.5Sn	45,000	(b)	--
Ti-5Al-2.5Sn	Ti-5Al-2.5Sn	27,000	10.5	--
Ti-5Al-2.5Sn	Ti-6Al-4V	45,000	10.5	--
Ti-5Al-2.5Sn	A-55	45,000	5.5	--
A-70	--	--	1	1
A-70	A-55	45,000	4.75	--
A-70	Ti-6Al-4V	45,000	10.5	--

(a) Side-bend specimens 6 inches long, 1-1/2 inches wide, and 3/16 inches thick were used.
(b) Crack observed at 10.5T due to lack of penetration in weld.

TABLE 6. SUMMARY OF HARDNESS DATA OBTAINED TO DATE[(a)]

Filler Wire	Hardness, Vickers Diamond Pyramid Hardness Numbers					
	Base Metal		Heat-Affected Zone		Weld Metal	
	Range	Average	Range	Average	Range	Average
			Ti-6Al-4V			
Ti-6Al-4V	303 to 359	331	333 to 370	346	322 to 365	352
Ti-6Al-4V[(b)]	303 to 359	331	334 to 351	343	337 to 377	361
Ti-5Al-2.5Sn	303 to 359	331	330 to 348	342	322 to 345	331
A-55	303 to 359	331	266 to 342	325	221 to 274	244
			Ti-5Al-2.5Sn			
Ti-5Al-2.5Sn	307 to 358	333	333 to 359	346	337 to 368	353
Ti-5Al-2.5Sn[(b)]	307 to 358	333	338 to 363	351	329 to 367	346
Ti-6Al-4V	307 to 358	333	335 to 375	361	326 to 359	346
A-55	307 to 358	333	332 to 370	350	209 to 281	236
			A-70			
A-55	245 to 272	254	243 to 291	262	210 to 258	224
Ti-6Al-4V	245 to 272	254	249 to 260	254	307 to 345	327

(a) Vickers diamond pyramid hardness using a 10-kg load.
(b) Low-heat-input welds.

Chemical Analysis

Chemical analysis of the welds made during this report period are given in Table 7. Base-metal and filler-wire analyses are given for comparison. Chemical analyses were used to obtain data on all elements except oxygen and hydrogen. Vacuum-fusion analyses were made to obtain oxygen and hydrogen contents.

TABLE 7. CHEMICAL AND VACUUM-FUSION ANALYSES OF BASE PLATE, FILLER WIRES, AND WELD METALS

Material	Filler Wire	Composition, per cent							
		Al	V	Sn	Fe	C	N	H_2	O_2
				Ti-6Al-4V					
Base plate	--	6.13	4.16	--	0.10	0.01	0.011	0.0056	0.1215[a]
Filler wire	--	6.78	4.06	--	0.11	0.01	0.011	0.015	0.1120
Weld metal[b]	Ti-6Al-4V	6.28	4.08	--	0.11	0.04	0.012	0.0092	0.1050
				Ti-5Al-2.5Sn					
Base plate	--	5.38	--	2.43	0.12	0.07	0.018	0.0027	0.154
Filler wire	--	6.15	--	2.57	0.40	0.01	0.012	0.029	0.1000
Weld metal[b]	Ti-5Al-2.5Sn	5.35	--	2.58	0.37	0.04	0.013	0.0192	0.1570
Weld metal	Ti-6Al-4V	5.95	3.06	1.70	0.12	0.03	0.012	0.0110	0.1190
Weld metal	A-55	1.13	--	0.63	0.11	0.06	0.016	0.0067	0.1690
				A-70					
Base plate	--	--	--	--	0.09	0.03	0.007	0.0073	0.317[a]
Filler wire	--	--	--	--	0.12	0.01	0.014	0.0059	0.148
Weld metal	Ti-6Al-4V	4.82	3.26	--	0.10	0.04	0.011	0.0090	0.1710

(a) Average of two analyses.
(b) Low-heat-input weld.

All of the analyses are within expected limits with the exception of the hydrogen content of the Ti-5Al-2.5Sn filler wire (0.029 per cent). A recheck analysis of this material confirmed these results.

The weld made in Ti-5Al-2.5Sn base plate with Ti-6Al-4V filler wire contained 5.95 per cent aluminum, 3.06 per cent vanadium, and 1.70 per cent tin. These changes in composition as compared with the welds made in this base plate when using matching filler wire were found to give about the same yield strength, better elongation, and lower impact properties.

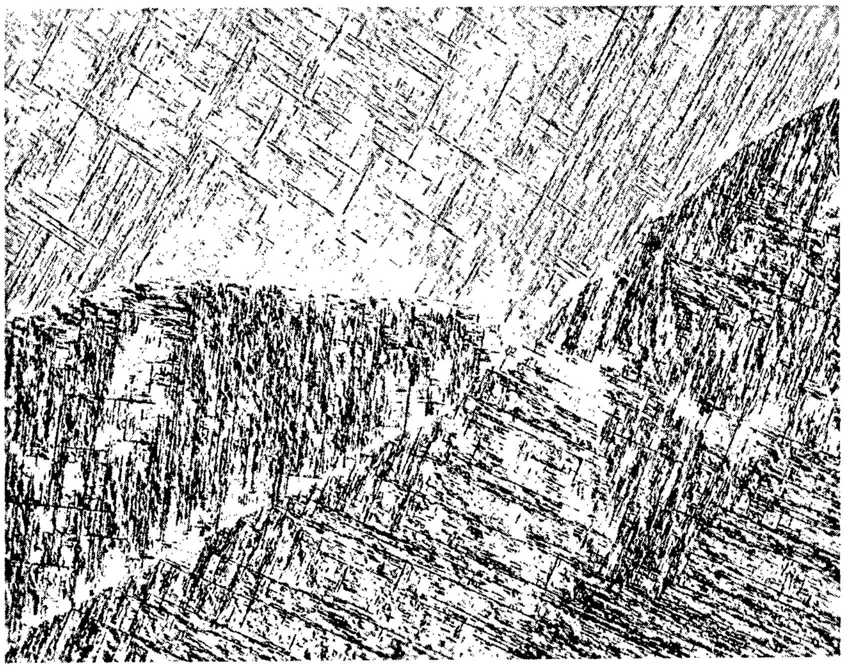
The weld made in Ti-5Al-2. 5Sn base plate with A-55 filler wire contained 1. 13 per cent aluminum and 0. 63 per cent tin. These changes in composition as compared with the welds made in this base plate with matching filler wire were found to decrease the ultimate and yield strengths considerably (65 per cent joint efficiency) and greatly improve the elongation and impact properties.

The weld made in A-70 base plate with Ti-6Al-4V filler wire contained 4. 82 per cent aluminum and 3. 26 per cent vanadium. The mechanical properties of this weld metal compare with the properties of welds in Ti-6Al-4V base plate made with matching filler wire. The yield strength of this weld was somewhat lower, and the ductility was higher than that of the welds in the Ti-6Al-4V base plate made with matching filler wire. The impact properties of this weld were about the same as those of the welds in the Ti-6Al-4V base plate.

The chemical composition of the manual weld made in Ti-6Al-4V base plate using Ti-6Al filler wire was not determined because of the lack of material.

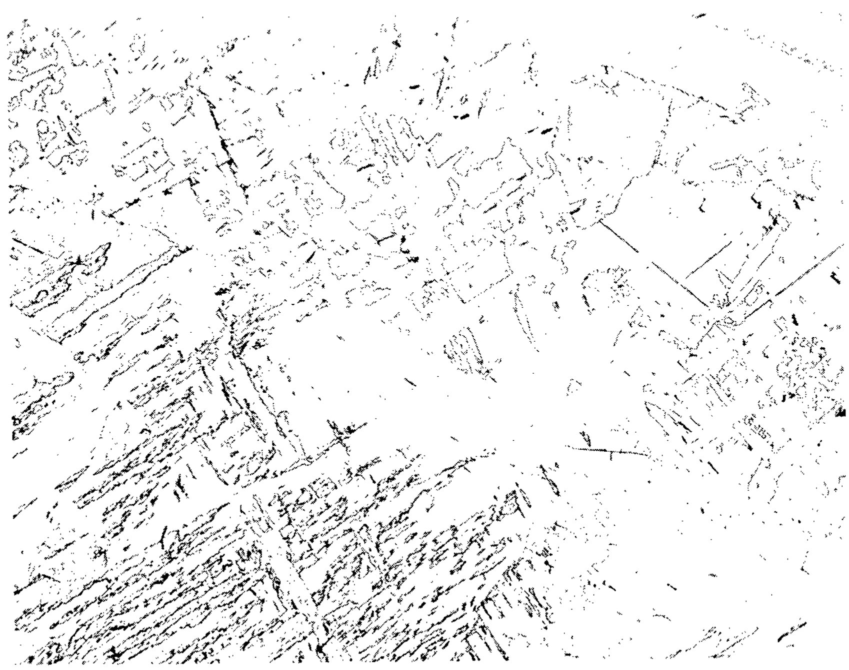
Metallographic Studies

The weld-metal microstructure of welds made during this report period are shown in Figures 2, 3, and 4. Microstructures of the low-heat-input welds in Ti-6Al-4V and Ti-5Al-2. 5Sn when using matching filler wire are not shown because of their similarity with those of the high-heat-input welds shown in Battelle's fourth bimonthly report, dated February 28, 1961.



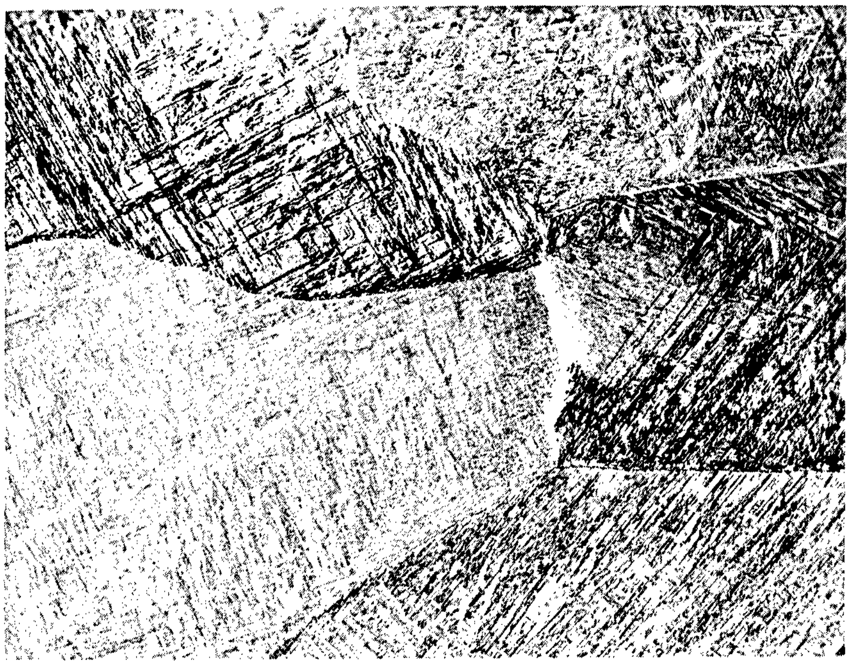
100X Etchant: 1.5 Per Cent HF, 3.5 Per Cent HNO_3, Balance H_2O N79248

FIGURE 2. MICROSTRUCTURE OF WELD METAL MADE WITH Ti-6Al-4V FILLER WIRE IN Ti-5Al-2.5Sn BASE PLATE



100X Etchant: 1.5 Per Cent HF, 3.5 Per Cent HNO_3, Balance H_2O N79249

FIGURE 3. MICROSTRUCTURE OF WELD METAL MADE WITH A-55 FILLER WIRE IN Ti-5Al-2.5Sn BASE PLATE



100X Etchant: 1.5 Per Cent HF, 3.5 Per Cent HNO_3, Balance H_2O N78435

FIGURE 4. MICROSTRUCTURE OF WELD METAL MADE WITH Ti-6Al-4V FILLER WIRE IN A-70 BASE PLATE

CONCLUSIONS

The following conclusions can be drawn from the results obtained to date:

(1) Cracking has not been a problem in any of the welds made to date.

(2) Heat input has a negligible effect on mechanical properties of welds made in the Ti-6Al-4V base plate with matching filler wire.

(3) Generally, variations in composition of the weld metal obtained by using filler wires of different composition than that of the base plate produced varied results:

(a) Weld metals made by depositing Ti-6Al-4V filler wire in Ti-5Al-2.5Sn base plate had about the same yield strength, elongation, and notch toughness as that of the base plate.

(b) Weld metal made by depositing A-55 filler wire in Ti-5Al-2.5Sn base plate had lower strength (65 per cent joint efficiency) but better elongation and notch toughness than that of the base plate.

(c) Weld metal made by depositing Ti-6Al-4V filler wire in A-70 base plate had yield strength considerably better than that of the A-70 base plate and as good as that of the Ti-6Al-4V base plate. Elongation of the weld was lower than that of the A-70 base plate and about equal to that of the Ti-6Al-4V base plate. Notch toughness of the weld metal was better than that of either base plate

(d) Weld metal made by depositing high purity Ti-6Al filler wire in Ti-6Al-4V base plate had the best notch toughness obtained to date in the program. The low interstitial content of the filler wire used in making this weld probably had a large effect on the notch-toughness properties.

FUTURE WORK

The Ti-13V-11Cr-3Al base plate was received at the close of this report period. In the future, it is planned to evaluate this base plate for tensile, bend, and impact properties and to make restraint test welds. In addition, weld joints made with filler wire that matches the composition of the base plate will be evaluated for tensile, bend, and impact properties.

Data are recorded in Battelle Laboratory Record Books Nos. 17387 and 17955, pages 1 through 13, and No. 17956, pages 1 through 18.

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